GUIDANCE MEMO PREPARED FOR THE TINY BEAM FUND

Industrial Aquaculture: History, Problems, Potential

Political Economic Review and Analysis of Socioecological Issues in Global Industrial Aquaculture Supply Chains

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Industrial Aquaculture Supply Chains Guidance Memo

History, Problems, & Potential Solutions for Sustainable Development

Authored by Dr. Timothy P. Clark and Dr. Stefano B. Longo*

*Dr. Clark is a Postdoctoral Fellow at the University of British Columbia, at the Institute for Oceans and Fisheries. Dr. Longo is a Visiting Researcher at Lund University and Associate Professor at North Carolina State University, Department of Sociology.

Aquaculture Development: Introduction and Overview

Our memo provides a critical overview of the political economy of aquaculture. This Guidance Memo outlines the rise of industrial aquaculture across the global food system. Readers will gain a descriptive understanding of aquaculture's recent development, as well as how industrial aquaculture supply chains are organized. The authors will provide readers with reflections on the obstacles to ethical and sustainable expansion, and make suggestions for governance and development.

History and Present of Aquaculture Development:

Aquaculture is the fastest growing sector of the world food system. This sector of the global food system is often regarded as an essential source of producing more protein for a growing global population. Largely due to overfishing and biodiversity loss that stems from pollution and climate change, the ocean's capacity to sustain increased industrial fishing has flatlined. In like manner, the capacity of the ocean system to sustain growth oriented fisheries has, since the 1980's, faultered. This stagnation occurred concomitantly with increased global demand for seafood. Since the late 1980's, capture fishing rates have hovered at or around 500,000 metric tons of fish species harvested per year on a global scale.

At the same time as captures have stagnated, the efforts to capture fish have increased. Application of new and more advanced technologies have been implemented, more and bigger boats have been added to the global fishing fleet, these boats are going further and further offshore to capture fish, and new species are sought after. These two contradicting trends point to grave potential concerns regarding the sustainability of wild fisheries.

Nevertheless, the expansionary nature of industrial seafood, international trade, and global demand did not stagnate. In the latter third of the 20th century, aquaculture production became a significant producer of seafood. Its value quintupled and its production quantity increased seven-fold within a single generation (Deutsch et al. 2007). Since the 1970's, and increasingly in the 1980's, aquaculture industrialized. Many national agencies, private enterprises, and international non-governmental organizations began promoting a model that saw "farming the seas" as an important initiative to

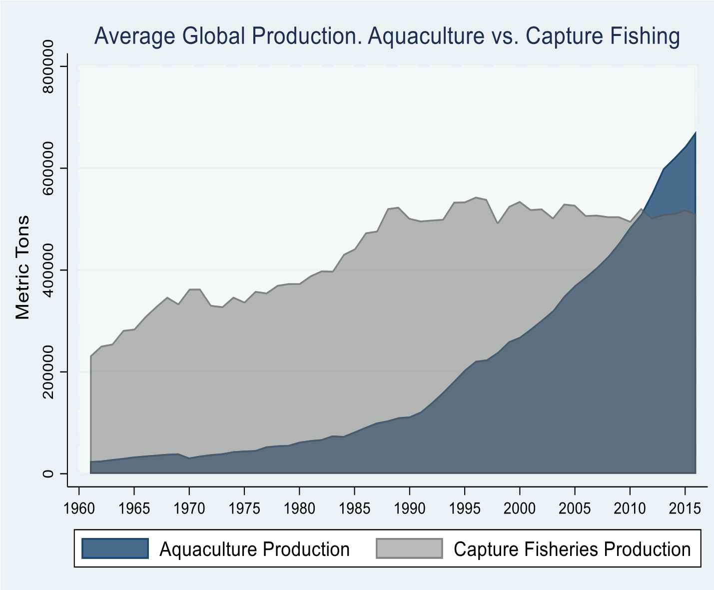
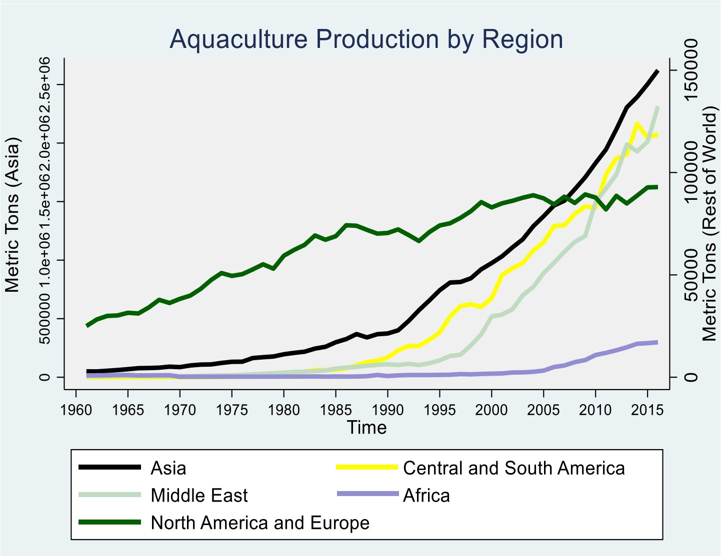


Figure 1 illustrates industrial aquaculture's meteoric rise, which began in the late 1980's. Scholars understand industrial scale aquaculture to mean controlled seafood rearing that is input dependent (feed/antibiotics/fertilizers/etc.), highly capitalized, and connected to global supply chains. Mechanization, monoculture, and a strict division of labor also characterize industrial scale aquaculture (Deutsch et al. 2007; Longo et al. 2014). These methods are socially and ecologically intensive, but highly effective at producing mass quantities of seafood commodities. Development scholars and policy leaders believe that aquaculture will continue to grow while capture fishing will remain stagnant (FAO 2020; World Bank 2013).



As Figure 2 illustrates, aquaculture growth across countries in Asia, Central and South America, and the Middle East occurred rather steeply. Conversely, aquaculture production in North America and Europe increased more steadily. Due to low levels of capital investment, aquaculture growth in African nations did not begin to increase measurably until the 21st century.
However, African aquaculture growth rates in the 21st century exceed other regions. Between 2000 and 2015, African aquaculture averaged 10.4% growth rates compared to Asia's 6% and the Americas' 5.7%

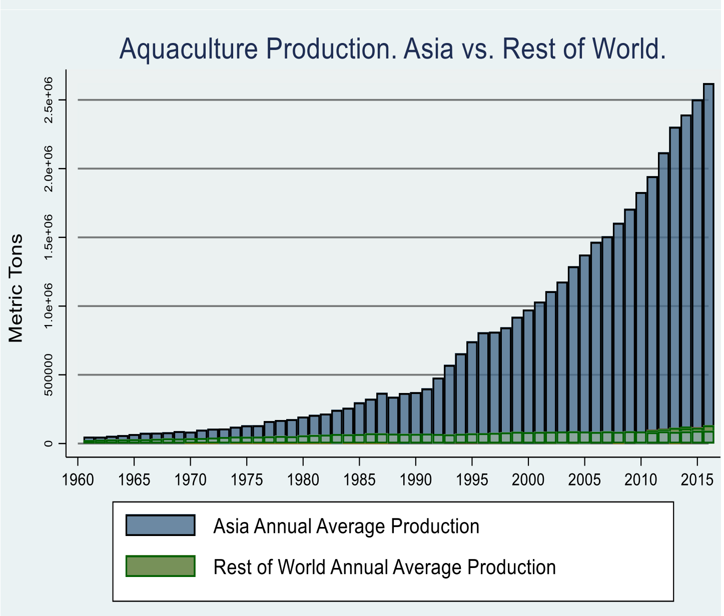


Figure 3 portrays Asian nations as the world's geographic aquaculture powerhouse. Indeed, the vast majority of industrial aquaculture production occurs in Asia. While several major seafood-producing nations—like India, Indonesia, Thailand, and Viet Nam—exist in Asia, Chinese aquaculture production accounts for the vast majority of aquaculture seafood produced in Asia. Indeed, Chinese aquaculture accounts for roughly 60% of *world* aquaculture production (FAO 2018).

Introduction (Continued)

increase the quantity and quality of food available throughout the world. Scholars understand industrial scale aquaculture to mean controlled seafood rearing that is input dependent. These inputs include feed, antibiotics, fertilizers, as well as energy. Industrial aquaculture systems are highly capitalized, and tightly connected to global supply chains. Mechanization, monoculture, and a strict division of labor also characterize industrial scale aquaculture (Deutsch et al. 2007; Longo et al. 2014).

These methods are socially and ecologically intensive, and highly effective at producing mass quantities of seafood commodities. This efficacy, along with marine ecosystem decline, accounts for aquaculture's eclipse of capture fishing production around 2009. Development scholars and policy leaders widely reckon that aquaculture will continue to grow while capture fishing will remain stagnant (FAO 2020; World Bank 2013). Thus, the gulf in production between aquaculture and capture fishing will very likely continue to widen.

The global seafood industry is arguably one of the most trade dependent industries on earth. About 40 percent of fish and fish products are destined for international markets. Much of these exports flow towards more economically affluent countries in the global North, who import more than they export (Bellman et al. 2016). International organizations like the FAO and World Bank universally expect seafood trade to increase, and justify these projections via the continued expansion of industrial aquaculture supply chains.

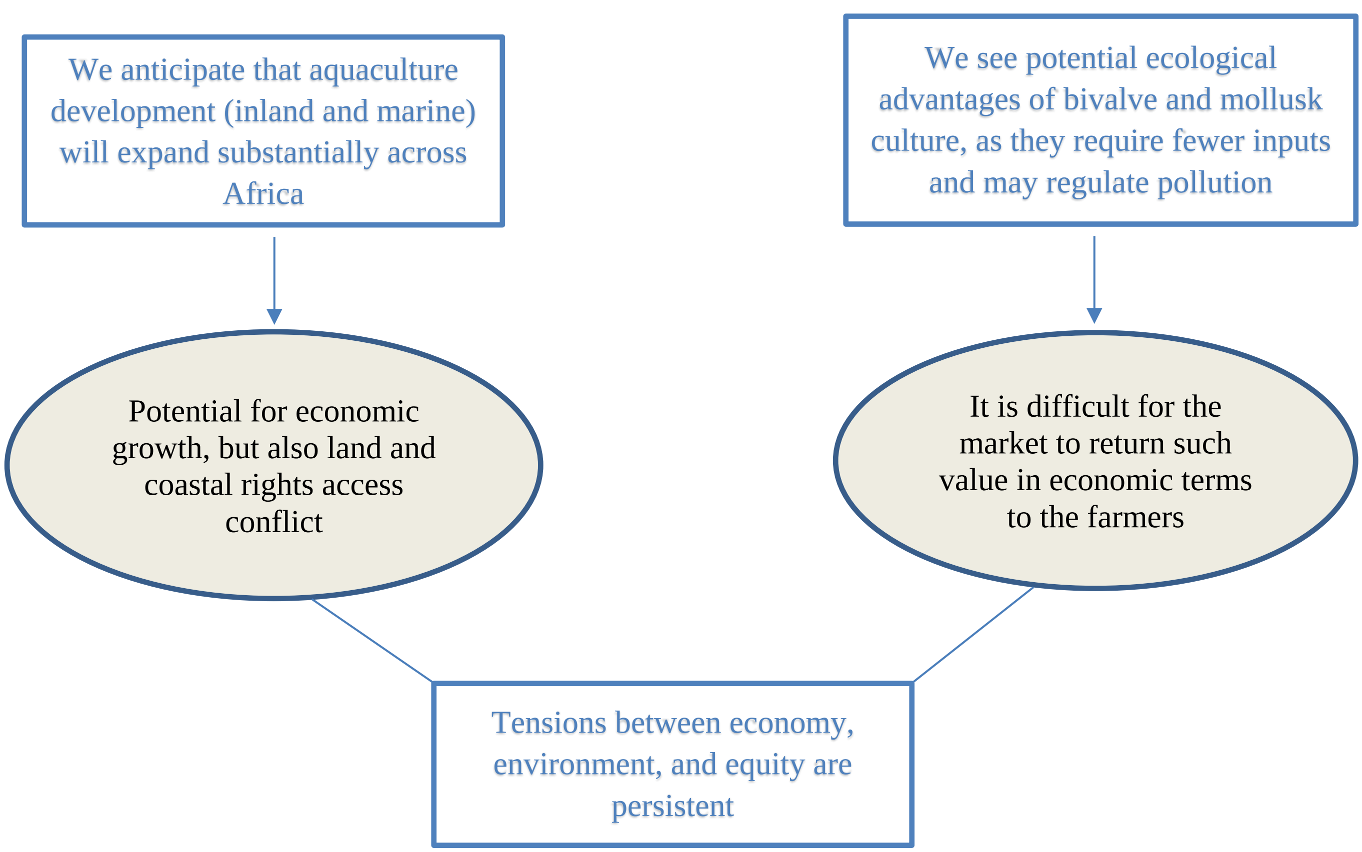
In spite of aquaculture's meteoric rise, the relationship between wild fisheries and aquaculture is crucial to understand when considering important social and ecological concerns. That is to say, when we want to understand aquaculture systems, their development, the role the play in the global food systems, as well as their social and ecological implications, we cannot understand them independently of capture systems. Not only are there biological and ecological links, but social ones as well.

Current and Future Trends

Type of Aquaculture	Millions of Tons Produced 2000	Millions of Tons Produced 2015	2000-2015 Change
Mollusks	10	20	+100%
Finfish	23	43	+87%
Crustaceans	3	6	+100%
Aquatic Plants	10	30	+300%

By volume, the most commonly produced aquaculture finfish species include carp, tilapia, catfish, trout and salmon. Leading crustaceans include varieties of shrimp, crawfish, and prawns. Commonly produced mollusks include species of oysters, scallops, Japanese carpet shell (a clam variety), mussel varieties, and cockles (FAO 2018). By weight, most aquaculture fish and aquatic species are procured in freshwater systems, like catfish, carp, and tilapia. It is anticipated that inland aquaculture, especially in rural areas of the global South, will continue to expand and industrialize (Edwards 2015).

Overall, there is considerable diversity in terms of species produced. The number of cultured aquatic species far outnumbers animal agriculture on land. In addition, in terms of individual animals, the number of aquatic animals that are reared in captivity far outnumbers the total number of all terrestrial animal produced. However, global trade in aquaculture concentrates on a handful of species; notably, salmon, catfish, shrimp, and tilapia (FAO 2020). Many of these species are ecologically intensive, and require high amounts of inputs and feeds to improve growth rates. While efficiencies in feed and input-output ratios have increased in the last 20 years, net usage of inputs continues to expand (Naylor et al. 2021).

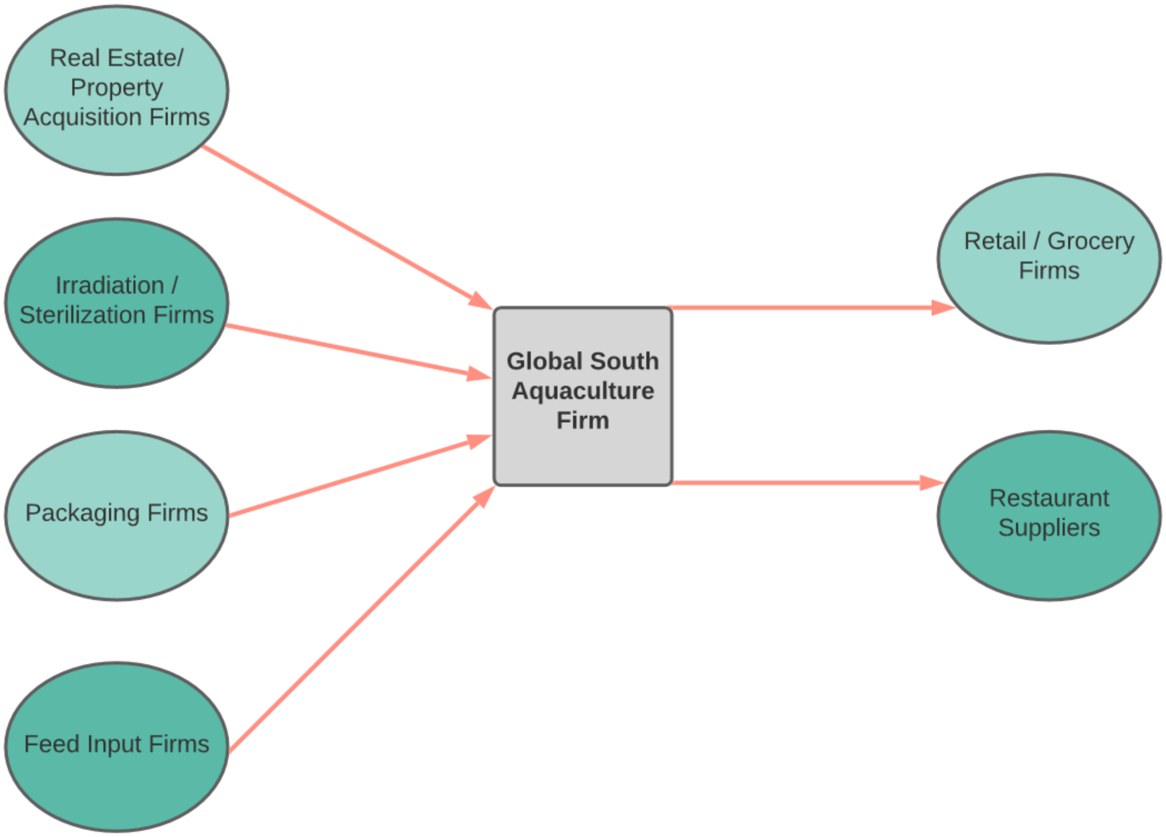


Major Industrial Firms

Company	Location	Revenue (Million USD)	Product Description	Customers
Mahura Nichiro	Tokyo, Japan	$8,327.8	Terrestrial livestock and seafood. Frozen food, canned food, fish sausages, pet foods, nutritional supplements, cosmetics	Distributes its products through distribution channels. Global exporter
Nippon Suisan Kaisha (Nissui)	Tokyo, Japan	$6,551.3	Produces/distributes fresh, processed and frozen sea food. Business portfolio comprises aquaculture, fishing, seafood processing, food products processing, logistics and fine chemicals businesses.	(Not Available / Not Disclosed)
Thai Union Frozen Products	Samutsakorn, Thailand	$4,238.1	Processor/manufacturer/distributor & exporter of frozen and canned seafood. Offers tuna, salmon, sardine, mackerel, bakery products, ready-to-eat products, shrimp, cephalopod and pet food.	Business presence across Europe, Asia-Pacific, the Middle East, Africa, Oceania and North and South America
MOWI	Bergen, Norway	$4,630	Farmed salmon, fresh fish, whole salmon, and processed salmon	Offers 7,190 consumer products in 2276 markets.
Dongwon Group	Seoul, South Korea	$2,601.8	Canned foods, instant foods, marine plant products, refrigerated processed meat, imitation crab meat/fish cake, frozen foods, and pet food	Distributes products through department stores, sales agencies and discount stores, mostly regional
Austevoll Seafood	Storebo, Norway	$2,650	Omega 3 oil, fish oil, fishmeal, frozen fish, and canned fish. Also involved in the rearing of salmon and trout	Has business presence in Norway, Eastern Europe, Africa, North America, Asia Pacific and South America
Cargill[1]	Minneapolis, USA	$113,490	Buys crops, stores and distributes worldwide. Also produces value added commodities for food feed and fuel	Provides products for retail and restaurants at global scale
Kyokuyo	Tokyo, Japan	$2,415	Frozen cooked food products, sliced raw fish and shell fish, and canned salmon and mackerel.	Sells frozen food products to restaurant chains and for industrial use as meals and for facilities.
Charoen Pokphand Foods (CP Foods)	Bangkok, Thailand	$17,192	Animal farming, animal feed production, raw material sourcing, meat processing, and manufacturing, distribution of food products.	Exports its products across five continents in more than 30 Countries. Also sells directly to large aquaculture farms.
Trident Seafood	Seattle, USA	Private Firm, not disclosed	The company produces and harvests Alaska pollock, Chilean seabass, cod, crab, flounder, haddock, halibut, salmon Alaskan, shrimp, steelhead, surimi paste, swordfish, and tilapia, among others	Caters to restaurants, education, casinos, colleges, universities, retailers, vendors, and warehouses.

[1] Cargill recently purchased EWOS, a major aquaculture producer out of Norway

Industrial Aquaculture Company Supply Chain Diagram



Key Insights from an Industrial Aquaculture Supply Chain

- **Aquaculture is input dependent, as suppliers provide food and sterilization related commodities like trash fish and pest / bacteria killing agents**
- **The wealthiest suppliers are generally property and energy companies centered in the EU and United States**
- **The aquaculture firm acquires its feed related inputs from less well capitalized, regional suppliers**
- **Common in the global food system, the firm sells most of its product to grocery and restaurant firms**
- **These buyers are primarily located in global North nations, and are much more well capitalized than the aquaculture firm**
- **These buyers source their seafood and aquaculture commodities from multiple different suppliers, which serves them well in price negotiations**

Characteristics of The Global Seafood Supply Chain

Many industrial aquaculture supply chains can be understood as "buyer-driven," which also characterizes the dominant form of supply chain governance and organization across the world food system. Buyer driven supply chains imply two important forms of power relations. First, the dominant actors are the "buyers," typically food retail firms. Massive grocery conglomerates are thus the most powerful actors in the world food system.

Why are grocery firms so powerful? Because they have succeeded in pushing economic competition upstream, to producers who lack the ability to determine the market and the market value for their product. This governance structure conveys several important implications. One, seafood producers in the global South are structurally pressured to supply low-priced seafood that meets firm standards for both quality and availability. Grocery stores want shrimp in their frozen and fresh sections constantly and at an abundant level. They rely on a myriad of global South fisheries to ensure this availability.

In countries where regulation on labor and ecological standards is lax or absent, this means heightened risk for worker exploitation and ecological degradation. For many fisheries and aquaculture systems in the global South, competition to meet market demand involves a race to the bottom. One pertinent example of this are the seafood supply chains of Thailand. These supply chains are increasingly aquaculture dependent, growing mostly shrimp and other high demand species for global North retail markets. In the Gulf of Thailand and Andaman Sea, wild fish stocks are severely depleted after generations of intensive fishing spurred by globalization and market development (Butcher 2004). The majority of wild-fish capture in Thai fisheries is now devoted towards supplying its aquaculture farms with inputs, or feed. This "feed' is composed of so-called "trash-fish," which simply means fish with no market value. Trash-fish could be juvenile species or low-trophic level fish that humans typically do not eat directly.

The Social Problems Associated with "Trash Fish"

- **There is no market value, so there is little incentive for paying crew**
- **Difficult to regulate, as species are often uncategorized and fishing often occurs in distant waters**
- **Creates environment where risk for worker exploitation and economic predation is high**

The social and ecological consequences of this practice in the global aquaculture supply chain have been devastating. Fishery scientists have long noted the potentially destructive effects of fishing down the food web (Pauly et al. 1998). Thai fisheries provide an extreme example of this, as the marine food web and greater marine ecosystem are profoundly affected by such fishing practices. In economic terms, Thai fisheries' catch per unit of effort has fallen drastically. It now requires a great deal more time and energy (i.e., effort) to catch the same quantity of fish. This declining economic efficiency translates to severe on-boat operating cost increases like fuel, boat maintenance, and crew wages. In ecological terms, the declining efficiency not only means less fish in the sea, but less species at the foundation of the marine food web. Trash species often have not had the time (i.e., life span) to reproduce and add new species to the ecosystem. Further, trash species also play important roles in cycling energy and calories through the marine food web. Their decline makes it difficult for marine systems to recover from biodiversity losses.

Nevertheless, the structure of the buyer-driven supply chain persists. In spite of the increased effort and ecological sacrifice, the pressure to supply cheap seafood remains. Thus, to remain competitive in the buyer-driven market, Thai seafood producers must not factor into the cost of their product the value of the time, labor, and ecological sacrifice involved in the production of its seafood—this would result in Thai farmed shrimp being quite expensive! To save money in the aquaculture supply chain, trash-fish (i.e., feed input) must be priced extremely low. While captains cannot change the nature of the depleted sea, or the price of fuel, they can affect the price paid to labor. As such, multiple news outlets and scholarly pieces have documented how Thai fisheries rely on severe labor exploitation and modern day slavery to procure seafood. Indeed, most fishing labor in Thai waters is currently performed by migrants from the neighboring nations of Cambodia and Myanmar (Burma). Most of these workers are impoverished and from rural communities. Reports have revealed shocking treatment of these workers, including debt peonage, violent coercion, and psychological abuse.

The second key implication regarding the power structure of buyer driven supply chains concerns regulation and responsibility for risk management. The power of the retail firm to supersede local and regional producers / suppliers also implies that there exists a gap in state power to effectively regulate the transnational firm and its suppliers. The nature of industrial aquaculture supply chains, which often rely on inputs such as trash-fish that can be caught in international waters, also limits regulatory efficacy.

> "Forced labour is routine. The workers we interviewed described being trafficked on to ships, trapped in jobs they couldn't leave, physical abuse, lack of food, long hours and awful working conditions. The worst thing for many of them was not being paid – the psychological harm and final indignity was the hardest to bear." HRW Asia, Cited in the Guardian 2018

Part of this limitation stems from the "race to the bottom" nature of the buyer driven supply chain. If a state cracks down on labor exploitation or sets meaningful regulation on ecological indicators, this can raise the price of their farmed seafood to uncompetitive levels. The buying firm, seeking to maximize cost savings, will seek lower priced seafood. There is thus no guarantee that regulation and improvements in one region or country will correspond with other nations' efforts. Cooperation across nations, where regional coherency is reached, is needed to mitigate supply chain risk.

The rise of such issues, along with the regulatory difficulties, within industrial aquaculture (and other food system) supply chains has given rise to new discourses concerning corporate social responsibility. Indeed, if the retail firm is the most powerful actor in the supply chain, then it may follow that appeals to these firms could serve to mitigate exploitation and pollution. This is the chief motivating logic that undergirds projects and advisory lists like Seafood Watch—sponsored by the Monterrey Bay Aquarium—that provide consumers and firms with tools to make informed purchases of more sustainable seafood. Similar efforts are now being made toward social issues, notably labor exploitation and slavery risk. Indeed, several international non-profit groups—specifically Liberty Asia, the Sustainable Fisheries Partnership, and the Monterrey Bay Aquarium—collaborated to form and advance the Seafood Slavery Risk Tool. The Slavery Risk Tool provides a likelihood rating that a fishery utilizes forced labor, human trafficking, or child labor on fishing boats. Ostensibly, the purpose of the risk tool is to better educate firms who can then manage their supply chains more effectively. Moreover, private consulting firms now offer paid services—marketed to global North firms—that trace seafood commodity chains for buyers.

Critical scholars reason that, while such ethical education tools mean well, they may run counter to the logics of corporate share holder responsibility. Ultimately, states and international organizations will have to act cooperatively to reduce these supply chain tragedies, like forced labor.

The Displacement Paradox

Aquaculture is frequently considered necessary for developing solutions to the problem of wild fisheries depletion. However, industrial aquaculture, especially for high value species like salmon, shrimp, and tuna, is input dependent. Inputs for aquaculture production require protein-rich feed. This feed is often procured via the fishing of low-value “trash fish,” or species that have little to no market value. Scholars have noted a troubling connection between low value trash fishing and increased pressure for labor exploitation in seafood supply chains (Clark and Longo 2021). In ecological terms, trash-fish are often valuable components of the marine food web. Thus, aquaculture feed requirements suggests that input-dependent, industrial aquaculture may add to demand for fish.

It is a commonly held principle that when one resource is being depleted, it can be substituted with another, e.g. farmed fish for captured fish. Recent scholarly research (Longo et al. 2019) in the journal *Conservation Biology* suggests that the growth of industrial aquaculture has not adequately displaced the demand and environmental impacts of industrial capture fishing. This research conforms to other scholarship on technological innovation and environmental impact, such as critiques of natural gas as a bridge fuel, and suggests that more deliberate efforts to regulate over-fishing will be needed alongside technological innovation. In short, we cannot assume that industrial aquaculture innovation will adequately alleviate pressure on marine wildlife and ecosystems without addressing the structure of the production system.

The Jevons Paradox

Environmental sociologists have long commented on the relationship between efficiency increases and environmental impacts. One paradoxical outcome in this relationship is the tendency for increased efficiency (e.g. better gas mileage in cars) to result in *increases* in total resource use (e.g. more fuel usage). This phenomenon is known as the Jevons Paradox, named after 19th century British economist William Stanley Jevons, who correctly predicted that innovation in the coal supply chain would lead to increased reliance, and greater production, of coal.

Here, we note that over the last half century, tremendous increases in the efficiency regarding the capture and rearing of fish has not led to a flattening of demand or reduced pressure on marine environments. In what should be a concern to activists and policy makers alike, a great deal of economic development in the global agri-food system is chiefly oriented around increasing profit and securing a greater share of the market. Massive food conglomerates often erode local food system autonomy and threaten food security. The industrialization of seafood and

POTENTIALLY TROUBLING TRENDS IN AQUACULTURE SUPPLY CHAINS

1. Feed represents 40-50% of industrial aquaculture costs. Thus, industrial scale aquaculture requires tremendous environmental inputs like soy, corn, and processed fish feeds.

2. Massive corporate conglomerates, like Archer Daniels Midland and Cargill, are buying out smaller pet and fish food firms.

3. This effort to secure feed and input production coincides with these firms’ investments in environmentally intensive aquaculture that requires considerable inputs.

4. Such investments also stimulate increases in the scale of production. Increasingly, firms are lobbying to lift bans and regulations on open ocean aquaculture. Open ocean aquaculture risks polluting marine territories and privatizing mass-scales of ocean territories.

Read more here:
Open Markets Institute
Reuters

aquaculture can threaten local fishing communities, as fishers lose access to coastal property and fish species that communities have relied on for generations become scarcer over time.

Overall, the Jevons Paradox suggests that the underlying motives behind economic production must be evaluated. Massive conglomerates and profit-driven production definitively require material expansion. This underlying requirement tends to outpace efficiencies in production and can threaten marine ecosystem stability. As stated, the environmental impacts often disproportionally hurt small-scale fishing people and fishers in the global South.

The Environmental Impacts of Ecologically Intensive Aquaculture

Regarding ecological impact, the type of species cultivated matters greatly. As noted previously, a common problem in global capture fishing is known as ‘fishing down the food web.’ This process involves the fishing of small, low trophic, or biologically immature species and indicates systemic overfishing and also risks undercutting the foundation of the marine food web. In industrial aquaculture systems, the inverse problem occurs: what scholars refer to as ‘farming up the food web,’ i.e. the controlled rearing of high trophic level species.

The energetic requirements of industrial aquaculture have grown steadily, at a rate of around 9% a year over the 1990s and through the 21st century. Notably, catching feed for inputs requires fossil fuel. During the catch and harvest process, fossil fuels supply energy for transportation, processing, and storing. Fossil fuel utilization varies depending on harvest techniques and distance traveled, but scholars estimated that global fisheries consume more than 12 times the total energy content of their catch (Tyedmers et al. 2005). This figure has likely increased over the years, as trash fish become scarcer. The second area of concern regarding trash fish inputs for high trophic level species is a matter of entropy. For example, estimates suggest that 1 kcal of salmon protein growth requires 25-50 kcals of protein input. In other words, caloric energy is lost over the process of rearing high market value species.

To mitigate these impacts, industrial aquaculture feed inputs have come to rely on soybean protein as vegetarian alternative, when applicable. However, soybean cultivation possesses its own environmental impacts, especially when grown at an industrial scale. Scholars of Latin American food systems have called contemporary industrial soybean monoculture farming a mechanism of colonization for its aggressive cultivation in ecologically sensitive areas in Latin America and, notably, rainforests (Altieri and Pengue 2006). In Brazil, more than 20% of all cultivated land is dedicated to export-oriented soy monocultures (Altieri 2009). Such practices rely upon high amounts of chemical fertilizers and pesticides, and also eat up land, forest, and soil that provides vital ecological services such as carbon capture and oxygen production. In short, relying more on soy to supply aquaculture species with feed will only exacerbate ecological problems elsewhere. Further, the highest values species that are reared and that are the focus on these changes are high-level carnivores. For example, on the trophic scale of 1-5, salmon are above a level 4. Thus, the efforts are focused on transforming these high-level carnivores into omnivores or vegetarians. This has consequences for the growth of these species and their metabolic processes.

In addition to energetic requirements from feed, large scale industrial aquaculture is also highly vulnerable to pests and microbes. Industrially raised salmon, for example, are highly vulnerable to sea lice. Species such as sea bream, shrimp, and sea bass also require massive amounts of antibiotics and other medications to prevent disease and parasites. In addition to the added energy requirements to the footprint of production, such practices also point to the reality that industrial scale aquaculture produces massive amounts of waste, excrement, and chemicals that, when discharged improperly or when pens are flooded, can pollute neighboring waters (Naylor et al. 1998; Frazer 2008; Longo et al. 2013). Chemicals used in aquaculture, like in other industries, can have serious environmental consequences. A recent large leak of chlorine used on an aquaculture facility in Norway resulted in the deaths of about 96,000 salmon and an extensive chemical leak into the Atlantic Ocean, with unknown consequences (Associated Press 2021).

Longo et al. (2013) developed a typology of ecologically intensive aquaculture species. In accordance with scholarly literature, they defined ecologically intensive as species that rely heavily on capture fisheries as sources of feed, involve high energy usage, emit pollutants into the environment, and correspond with negative impacts on wild stocks. The following table is reproduced from their study.

Species group	Common name	Scientific name	Ecologically Intensive Characteristics of Aquaculture Production
Tuna	Atlantic blue fin	Thunnus thynnus	Energy-intensive; impacts on wild stocks; local ecosystem pressures; highly dependent on marine capture fisheries
	Pacific blue fin	Thunnus orientalis	Energy-intensive; impacts on wild stocks; local ecosystem pressures; highly dependent on marine capture fisheries
	Southern blue fin	Thunnas maccoyii	Energy-intensive; impacts on wild stocks; local ecosystem pressures; highly dependent on marine capture fisheries
Salmon and Trout	Atlantic salmon	Salmo salar	Energy-intensive; impacts on wild stocks; local ecosystem pressures; highly dependent on marine capture fisheries
	Coho salmon	Oncorhynchus kisutch	Energy intensive; impacts on wild stocks; local ecosystem pressures; highly dependent on marine capture fisheries
	Rainbow trout	Oncorhynchus mykiss	Energy-intensive; local ecosystem pressures; highly dependent on marine capture fisheries
Shrimp and Prawn	Giant tiger prawn	Penaeus monodon	Energy-intensive; local ecosystem pressures; highly dependent on marine capture fisheries
	Whiteleg shrimp	Penaeus vannamei	Energy-intensive; local ecosystem pressures; highly dependent on marine capture fisheries
Mediterranean finfish	European sea bass	Dicentrarchus labrax	Energy-intensive; local ecosystem pressures; highly dependent on marine capture fisheries
	Gilthead sea bream	Sparus aurata	Energy-intensive; local ecosystem pressures; highly dependent on marine capture fisheries

This typology can serve as a framework for new and emergent forms of aquaculture species production. In general, we advise against large scale, globalized cultivation of any of these species. Ethnographic and historical social science suggests that communities of peoples relied on the local and regional harvest and raising of these species for generations to provide sustenance. However, these were wild capture fisheries oriented around satisfying human need at smaller scales. Cultivation of ecologically intensive species should be reduced in favor of local and regional systems operated at smaller scales, and managed by communities for their own needs.

Aquaculture and Animal Ethical Concerns

In addition to the ecological concerns associated with intensive industrial systems of aquaculture production, it is important to highlight issues associated with animal ethical concerns. Ethical matters are discussed above in relation to human well-being and forced labor. However, one area of concern that is rarely discussed when it comes to aquaculture is the welfare of aquatic animals associated with modern systems of industrial production. There are numerous well-known debates about the welfare and ethics associated with industrial production of animals for food. These are largely focused on terrestrial domesticated animal production systems. Yet, scholars are increasingly advancing the discussion of animal welfare and food production of aquatic species (Sneddon et al. 2018; Jacquet et al. 2019). This is a matter that tends to be overlooked as these species inhabit underwater spaces that are largely out of sight for most humans.

Industrial production of animals on land has many similar qualities as underwater production systems including mass production, which brings a large number of animals close together in relatively small spaces. As on land, the consequences of these conditions for aquatic animals includes decrease access to space and stimuli, increased disease, and high death rates. The crowded conditions can have severe consequences for some species, such as salmon where parasites and disease spread easily and rapidly. In the case of salmon there have been several large-scale die-offs, where hundreds of thousands of fish are lost to disease in a single event. As stated, these events often go largely unnoticed as they occur at sea.

Further, aquatic species (particularly non-mammals) are often considered to be unlike terrestrial species, thus, for example, lacking the sentience that those animals on land display. This is an issue that is increasingly debated as some aquatic species (beyond mammals) have displayed behaviors that demonstrate complex cognitive abilities—often associated with "intelligence"—including communication, tool use, and recognition of individual animals. For example, octopuses have exhibited advanced learning behaviors, and it is suggested that they likely have some level of consciousness, which includes the experiencing of pain and suffering (Godfrey-Smith 2017). Nevertheless, as the numbers of octopus decrease in the wild, there are increasing efforts by multi-national firms to farm them in industrial systems (Scigliano 2020). These efforts have been plagued by natural and technical challenges, including species-specific characteristics that make them difficult to domesticate and produce in captivity, and can have detrimental effects on the health and welfare of individual animals. This has spurred scientists to suggest to policymakers that the development of industrial octopus aquaculture farms should be prohibited (Jacquet et al. 2019).Overall, issues of animal well-being and ethics should not be overlooked in this sector. Surely aquatic species are very different than terrestrially domesticated animals, and this may be precisely the reason that more careful attention should be paid to these matters.

Recommendations for Sustainable Development

Seafood from aquaculture production has seen a meteoric rise in recent decades. This aspect of the global food system has been contributing significantly to the global seafood supply. While immensely productive, this dramatic rise does not come without costs and challenges, both social and ecological. The intersecting political, economic, and ecological nature of the issues we have discussed renders them problematic to uniform policy solutions. We propose that far-reaching modifications are needed in order to address concerns associated with modern industrial aquaculture production systems. There are many challenges as far as advancing policies that ensure healthy, viable marine systems and equitable social outcomes.

We stress that there are some models of fish-farming and fisheries management that food system advocates could seek to promote. As mentioned previously, mollusk cultivation under certain parameters can promote ecological benefits. For example, the Billion Oyster Project in New York City has promoted sustainable oyster cultivation to help improve water quality in the New York Harbor. The project uses recycled oyster shells to establish habitat for oyster growth. While grown for ecosystem services and not food, this project provides an example for how aquaculture can promote ecological sustainability. Over time, a well-regulated mariculture system could promote local food security and water quality in sustainable fashion.

Further, we emphasize that the highest value species that are mass produced in intensive aquaculture (such as salmon and shrimp) are largely produced for affluent markets in wealthy nations. Thus, their contribution to global food security is highly questionable. Increased attention should be paid to the ways in which intensive industrial aquaculture systems may increase inequalities around the world when ecologically and social valuable aquatic and coastal areas are transformed into large-scale animal rearing operations. The environmental local consequences associated with such systems can harm local fishing people and coastal communities. This is especially troubling when production occurs in the global South for export to wealthy nations.

Historical examples of well-managed fisheries and farmed fish systems abound as well. These systems often share two socioecological commonalities. Typically, they work with—not against—the natural biology of marine species. Two, fish production is more grounded in meeting local community consumptive demand. As a result, these systems are dictated less by abstract economic imperatives that can drive overproduction and tend to overshadow social and ecological goals. Thus, solutions to current problems involve rethinking the social and ecological assumptions of production.

We therefore caution against falling back on common regulatory views that emphasize market mechanisms and new technologies as the central solutions for sustainable and equitable development in seafood production. While these aspects will certainly need to be deliberated and incorporated into efforts toward sustainable aquaculture development, we suggest that they must be part of broader objectives which center on reduced commodification and food sovereignty concerns. That is, with a recognition of the social paradoxes mentioned in this report, we are less optimistic about straightforward market mechanisms or technological fixes that maintain the economic structure of the system, than social changes and policies that are based on increasing the viability of smaller-scale seafood producers as well as the promotion of smaller scale, local and regional supply chains that produce species more in-tune with their ecological surroundings and less reliant on environmentally intensive inputs. Further, we emphasize the need to prioritize marine ecological health, biodiversity, and welfare (both human and non-human), rather than economic returns and growth.

We suggest that the direction of aquaculture systems towards increased consolidation of market share by large conglomerates and large-scale industrial systems focused on economies of scale must be reconsidered in terms of their long-term social and ecological viability. We also see a benefit of shifting greater attention to culturing species lower on the food chain (such as mussels and oysters), but recognize that this shift alone, without considering the other issues mentioned above, would not be adequate.

Data and References In Report

We obtained data on aquaculture via accessing publicly available statistics in the United Nations Food and Agriculture Association (FAO), more specifically FAO Stat, which offers country level data on a variety of food system indicators. We organized country level, time-series data into STATA to produce graphs and figures utilized in this report.

We obtained data on supply chains and firms from two sources courtesy of North Carolina State University Library. Supply chain figure was informed via a supply chain analysis function within Bloomberg Terminals, a software program that enables research professionals to access real time financial data and economic trends within and across firms. We also utilized Business Search Complete from the North Carolina State Library to access company level reports on financial data, products offered, and earnings.

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